Ni. MS-I

Report No. 34-65

Control No. U-65-34A

Copy No.

Thiokol

RADAR ATTENUATION MEASUREMENTS

FINAL REPORT

Contract NAS 8-11635

Prepared for

George C. Marshall Space Flight Center

Huntsville, Alabama

THIOKOL CHEMICAL CORPORATION
HUNTSVILLE DIVISION
HUNTSVILLE, ALABAMA

Thiokol

CHEMICAL CORPORATION

HUNTSVILLE DIVISION
HUNTSVILLE, ALABAMA

RADAR ATTENUATION MEASUREMENTS

FINAL REPORT

16 November 1964 through 15 May 1965

Principal Investigator: G. W. Sanford

Date of Publication: 14 May 1965

Prepared for

George C. Marshall Space Flight Center

Huntsville, Alabama

APPROVED BY:

B. D. Herbert
Director
Project Management

G. F. Mangum
Project Manager
Research and Special Projects
Project Management

CONTRIBUTORS

J. A. Farr, Jr.

F. J. Scrable

R. C. McCauley

R. E. Bradley

CONTENTS

TABLES

FIGURES

iv

CONTENTS (Cont'd)

FINAL REPORT

RADAR ATTENUATION MEASUREMENTS

NASA Contract NAS 8-11635

16 November 1964 through 15 May 1965

SUMMARY

Eight rocket motors (two TX-280, three 2KS36 Genie, and
three TE-29 Recruit) were static tested to determine the extent of
radio interference produced by the ionized exhaust gases just aft of
the nozzle exit plane. Attenuation measurements were made on the
X (10 KMC), Ku (20 KMC) and Ka (30 KMC) bands. Data were recorded
on FM tape and oscillograph traces in all tests.

The FM tapes were transmitted to Marshall Space Flight Center
for evaluation and the oscillograph records were retained by Thiokol
Chemical Corporation. A review of these records indicates that, for
all motors, attenuation during motor operating time was essentially
below 0.25 db, which is considered the resolution capability of the
system. Attenuation peaks were encountered in all motors during
ignition and, to a lesser degree, during motor tail-off.

The theoretical calculations of attenuation levels made prior to
the tests indicated a very low attenuation during motor operating time.
This prediction was essentially confirmed by the actual test data.

Correlation of static test data with flight data was not within the
scope of effort on this program. This will be accomplished under
direction of Marshall following extensive review of the FM tape data.

INTRODUCTION

Thiokol Chemical Corporation - Huntsville Division, has com-
pleted a program of radar attenuation measurements on two TX-280
motors, three TE-29 Recruit motors and three 2KS36 Genie motors
for the George C. Marshall Space Flight Center, Huntsville, Alabama,
under NASA Contract NAS 8-11635. The period of performance of this
contract covered six months, from 16 November 1964 through 15 May
1965.

The program was conducted to determine the extent of radio interference produced by the ionized exhaust gases just aft of the nozzle exit plane. In pursuit of this objective measurements were made during the tests in the X, Ka, and Ku bands.

TECHNICAL DISCUSSION

Equipment Preparation

The microwave equipment available at the start of this program did not have provisions for Ku band measurements. A modification to the transmitter and receiver mounting fixture was made to allow attachment of a third set of horns within the same plane. A sketch of the modified fixture is shown on Figure 1. Appendix A lists the microwave equipment used in this program. The Ku band position replaced the previous X band location and the X band position was moved to a horizontal path with mountings adaptable to the 10-inch aperture horns and lenses. After frame modifications were completed, the fixture was moved into the microwave laboratory and all microwave components were mounted and antennas aligned.

After completion of component mounting and alignment, each system was tested for proper operation in the following manner.

1. Power was applied to the Klystrons and a dual channel oscilloscope was connected to the transmitter and receiver crystal mounts.

2. Each Klystron was tuned for peak output and then permitted 30 minutes to stabilize after which it was retuned for peak output.

3. A frequency measuring device consisting of a precision cavity wavemeter, a standard gain horn, and a crystal mount, was used to determine the output frequencies of each transmitter and the Klystrons were adjusted to the pre-determined test frequencies of 10, 21, and 30 KMC.

4. All crystal mounts on the system were tuned for peak output.

5. Test calibrations were made repeatedly on each system by adjustment of the precision variable attenuators to test proper operation.

6. Each system was operated for several hours to test stability and reliability.

A specially fabricated cable, approximately 120 feet long, was used to connect the Klystron power supplies which were mounted in the test pit instrument room, to the Klystron signal generators on the equipment frame in the test bay. To provide additional conductors for the Ku Band Klystron, the existing cable was dismantled and reconstructed. All new connectors were employed and after fabrication, each conductor was checked for proper connection and isolation. The cable was then attached to the Klystron power supplies and normal voltage was applied. Ultimately, the beam voltages being applied were doubled above the normal value to test for high voltage leaks and possible arc-over.

A final system test was made which consisted of attachment of the entire system using the new cable. Steps one through three of the original checkout were briefly repeated, thus completing the lab checkout of equipment.

A schematic diagram of the test setup is shown on Figure 2.

Lens Pattern Tests

Prior to assembly, additional antenna pattern tests were conducted on each microwave system. This was done to improve existing measurement data on the six-inch aperture antennas and lenses as well as to define the patterns for the new ten-inch aperture antennas and lenses for the X Band system.

For each pattern test, the microwave equipment was located on the test bench with the transmitting antenna and the receiving antenna adjusted, in line with one another, and at the design focal length position. As shown on Figure 3, a guide track assembly was located in line and centered on the antenna path centerline similar to an optical test bench arrangement. A Plexiglas[1] sheet was attached to a holder which was guided by the track assembly so the plane of the Plexiglas was perpendicular to the track centerline. The Plexiglas sheet was inscribed with concentric circles centered on the antenna centerline to permit the accurate location of microwave absorber material (Eccosorb AN 73) discs. The holder was also arranged to allow it to be moved from the position of one lens to the other at a slow constant speed. As the nature of the Eccosorb material is such that it highly attenuates microwave energy over the frequency range of systems with a very low reflectivity (approximately 1 percent), two pieces of the material with an aluminum foil section sandwiched in between were used to simulate complete measurable attenuation. Under conditions where the discs formed of this attenuating section were larger than the microwave beam section, the signal path was obstructed and no measurable receiver signal level could be obtained. However, when the disc diameter was

1. Trade Mark of Rohm & Haas Co., Philadelphia, Pennsylvania.

smaller than the beam diameter, a detectable receiver signal would result which could be related to power levels by substitution type attenuation calibration. Thus, by positioning various diameter discs within the beam path and by moving various sized discs at a constant rate over the entire path while recording the received signal level, the energy profiles could be determined. The recording technique used for this purpose was an oscilloscope adjusted for single sweep at a rate equal to the motion rate of the holder. By use of a scope camera, the required recordings were thus made by first operating the camera shutter, second, initiating holder travel and scope sweep simultaneously; and finally, after the desired holder travel, closing the camera shutter. In each case, a precision attenuator was used to relate level indications to attenuation db. and data reduction was accomplished manually from this calibration.

To determine the optimum antenna spacings, the tests described in the previous paragraph were conducted at various antenna spacings near that indicated by the design focal lengths. This information was later used for adjustment of the components on the test fixture. The data from all antenna pattern tests is presented in Tables I, II, and III.

Theoretical Calculations

Theoretical calculations were made to predict the radar attenuation of the three types of motors prior to testing. The method of Fleischer was used for these calculations. The computations were rather complex so a small computer program was written to solve the electron concentration in the chamber. Electron concentrations in the exhaust may be calculated either by assuming no attachment and non-equilibrium of electrons or by assuming attachment and non-equilibrium. The methods are outlined below. Collision frequencies were estimated by assuming that HCl and water have the same collision cross section and that all other species are 20 percent of this[1].

Although it is known that electron temperatures are several thousand degrees higher than their surroundings no good estimate is available. Hence, chamber temperature was used when electron temperature was required.

The radar attenuation was determined from the curves generated by Balwanz[2]. Two methods may be used to determine electron concentrations at the exhaust plane. The first, and probably least exact, assumes no attachment of electrons to other species in the gas and assumes a pure adiabatic expansion. In this instance the electron con-

1. H. F. Chalcote and H. Silla, Bull. of the 18th Meeting JANAF, Volume 3, p. 3, June 1962.
2. W. W. Balwanz, NRL Report 5388 (1959).

centration is shown as:

$$n_e = \left(\frac{P_e}{P_c}\right)^{1/\gamma} n_c \qquad\qquad I$$

where:

n_e is the electron concentration at the exhaust plane (electrons/cc)

n_c is the concentration in the chamber

P_e and P_c the exhaust and chamber pressure, respectively

γ is the ratio of specific heats

A second method which assumes attachment uses a curve generated by Chalcote[1]. This curve is shown on Figure 4. The data required to use this curve are electron concentration in the chamber (n_{ec}), the recombination coefficient (α_{rc}), the characteristic velocity (C^*, cm/sec), the throat diameter, the average ionization potential of the species (V_i), the chamber temperature, and the pressure ratio (P_c/P_e). V_i must be in units of calories/mole.

A Thompson 3-body recombination, which is the most probable, is:

$$\alpha_c = 6 \times 10^{-6}\ P/T \qquad cc\ atm/sec.\ °K$$

Collision frequency: The collision frequency (γ) is:

$$\gamma = \left(\frac{8\ KT}{\pi\ M_e}\right)^{1/2} \Sigma Qn \qquad\qquad II$$

where:

K	= the Boltzmann constant	1.38×10^{-16} erg/°K
M_e	= Mass of electron	9.11×10^{-28} g
T_e	= Electron temperature	
Q	= Collision section	
n	= Particle Density	M_e/cc
	$= 0.734 \times 10^{22}\ P/T$	

1. H. F. Chalcote, CPIA Radar Attenuation Symposium 1963, CPIA Publication Number 6.

6

This equation reduces to:

$$\gamma = 4.558 \times 10^{22} \; \frac{T_e^{1/2} \; P}{T_{ex}} \; \Sigma_i N_i Q_i \qquad \text{III}$$

where:

T_{ex} = Exhaust temperature

P = Exhaust pressure

N_i = Mole fraction of ith specie

Q_i = Collision cross section of ith specie

In the calculations at hand the collision cross sections of HCl and H_2O are considered to be the same and are shown on Figure 5. The data are from Altshuler[1]. The collision cross sections of all other species are considered as 20 percent of this value[2].

Three propellants were calculated, the TPE-8035 used in the Recruit, the TPL-8183 used in the TX-280, and the ANP-512-DS-Mod 3 used in Genie. In all propellants 110 ppm of sodium were assumed and in all but the ANP-512-DS-Mod 3, which contains $KClO_4$, 65 ppm of potassium were assumed. Free aluminum and chlorine as well as the concentrations of water, HCl, and monatomic hydrogen were taken from the thermochemical calculations. The free electron concentration in all three cases is too low to use the curve on Figure 4. Therefore, only the non-attachment calculations were made. The results are shown in Table IV, using radar frequencies of 10, 20, and 30 KMC.

The calculated attenuation at the exhaust plane of all three propellants was considered low. The maximum being 0.75 db/meter in the Genie motor with 10 KMC radar. From these calculations it must be assumed that any large amount of attenuation will be caused by afterburning. All three propellants are underoxidized, that is, they contain large amounts of CO and H_2 in the exhaust products. On mixing with air they could easily react with the evaluation of heat and the subsequent ionization of the metallic species thus causing attenuation of a radar signal.

At the time these calculations were made, the attenuation results obtained were considered quite low. However, the actual data obtained during the static tests indicate that the error in the theoretical calculations was not nearly as great as originally expected. No firm correlation can be drawn because the predicted and actual attenuation values are below the resolution capability of the system.

---

1. S. Altshuler, Phys. Rev. 107, 114 (1957).
2. H. F. Chalcote and H. Silla, Bull. of the 18th Meeting JANAF, Vol. 3, p. 3, June 1962.

Test Set-Up

The tracks for the microwave fixture were first mounted and aligned in the test bay in such a way that the fixture centerline would be centered on the test bay thrust centerline and would intersect the thrust plate at a point 36 inches above the base plate. The microwave fixture was then positioned on the tracks and all instrument cables and power cables were attached. The signal conditioning and recording equipment was then set up in the instrument room per the following:

Transducer

1. Pressure: 2 each Baldwin Model STD. 2000 psig pressure pickups.

2. Vibration: 1 each Endevco Model 2242 vibration pickup with local Model 2416 amplifier.

3. Radar: X Band - 1 transmitter input, 1 receiver input and 1 reflected signal input from type 1N21-C microwave diodes.

   Ku Band - 1 transmitter input and 1 receiver input from type 1N26 microwave diodes.

   Ka Band - 1 transmitter input and 1 receiver input from type 1N53C microwave diodes.

4. Current: Ignition Blip.

Calibrations

1. Pressure: Dead load using Ashcraft Tester 0,400, 800, 1200, 1600, 2000 psig. Approximate galvonometer deflection desired was 3 inches at 1600 psig.

2. Current: 1 inch galvonometer deflection was desired at 8 amps.

3. Timing: 1000 c.p.s.

4. Vibration: 10 Mv/G, T.D. output, 100 Mv/G amplified output.

5. Radar: As required per test. (Calibration of the variable attenuaters was performed by the U.S. Army Missile Command Calibration Center and the results are presented as Appendix B.)

8

Recording Equipment

1. Ampex FR-100 Tape, 60 IPS

Channel	Head Position	Type	Function
1	13	FM	Ka Band Receiver
2	2	FM	X Band Receiver
3	3	FM	Ku Band Receiver
4	4	FM	Ka Band Transmitter
5	5	FM	X Band Transmitter
6	6	FM	Ku Band Transmitter
7	7	FM	X Band Reflected
8	14	FM	Vibration
9	9	FM	Pressure
10	10	FM	Timing
12	12	Direct	Audio

2. Oscillograph, C.E.C. Type 5-119, 40 IPS

Spot Position	Galvonometer	Conditioning	Function
1	317	Shorted	Edge Zero Reference
2	326	Generator	Timing
3	323	Direct	Current (Ign.)
4	323	Direct	Voltage (Ign.)
5	323	"Dana"	Ka Band Receiver
6	323	"Dana"	X Band Receiver
7	317	Shorted	Record Center
8	323	"Dana"	Ku Band Receiver
9	323	"Dana"	Ka Band Transmitter
10	323	"Dana"	X Band Transmitter
11	323	"Kintel"	Ku Band Transmitter
12	323	"Kintel"	X Band Reflected
13	348	Direct	Chamber Pressure
14	348	Direct	Chamber Pressure
15	317	Shorted	Edge Zero Reference

Photographic Coverage

1. Black and white stills before and after firing.
2. Color, motion pictures, 64 F.P.S. of tests.
3. Black and white still during test (Plume).

Mechanical Set-Up

Restraint equipment was designed and fabricated to provide for adaptation to the motors involved with no thrust measurement. In addition, this equipment was designed to restrain the motors at the thrust centerline of the bay and at a centerline height of 36 inches above the thrust base.

The following is a list of components by drawing number:

1. TX-280 Motors: 1 stand with Flange Restraint Ring, Thiokol Drawing No. CR-42618.

2. TE-29 Motors: 2 saddles per Thiokol Drawing No. CR-42615, and a Modified TX-19 Thrust Adapter, Drawing No. 41519-A.

3. Genie Motors: 2 saddles per Thiokol Drawing No. CR-42612, and thrust adapter per Drawing CR-42462.

Test Operation

During the static testing of these motors, special experiments were conducted by the Boeing Company as well as extensive photographic coverage by NASA.

In each test, the following basic sequence was followed with only such deviations as are noted:

1. All test equipment and instruments were checked out to insure proper operation.

2. All interested test groups were notified of test sequence initiation.

3. Pre-test calibrations on all channels were made inclusive of a complete voltage reference type calibration for all tape channels.

4. The motor was installed in the test bay and aligned.

5. The microwave frame was positioned and secured.

6. Pressure pickups were dead load calibrated and attached to the motor.

7. Microwave receiver channels were calibrated by introducing attenuation by means of the precision attenuators in the receiver wave-guide system.

8. Before firing still photographs were taken.

9. All interested test groups were notified to prepare for initiation of the count down.

10. The firing circuits were armed.

11. The count down was initiated and the motor fired at T = 0 with tape start at T - 8 seconds, oscillograph start at T - 5 seconds, and 64 feet per second camera start at T - 2 seconds.

No equipment malfunction was noted throughout all eight motor firings on any of the microwave systems, the signal conditioning systems, or the recording systems. One oscillograph test record was partly damaged in development, however, thid did not affect the tape data which was the primary data source.

Figures 6 through 11 show typical views of the motors after testing. Figures 12, 13 and 14 show the exhaust plumes of a typical TX-280, Genie and Recruit, respectively, during the test.

Data Analysis and Conclusions

Operation of motors was normal in all tests. Instrumentation measurements recorded both on oscillograph records and FM tape appeared to be of high quality. The FM tapes have been transmitted to Marshall Space Flight Center for detailed analysis.

The oscillographic analog data recorded as covered in the section on Test Set-Up, has been studied extensively without success with respect to determination of sufficiently accurate multi-frequency attenuation levels to permit the electron density and collision frequency determinations necessary to the intended analysis. For all intensive purposes, the level of attenuations encountered on all the motors, with the exception of ignition and tail-off portions, was below the measurement resolution of the system. This conclusion is essentially confirmed by theoretical predictions presented in this report.

The oscillograph records have not been reduced and replotted; however, for information purposes, typical traces for the TX-280, Genie and Recruit are shown on Figures 15, 16 and 17, respectively. These sections of the traces show typical attenuation values for all bands which are essentially the same until tail-off. The traces are presented to show trends only, since zero shifts and fluctuating in power levels must be considered in obtaining an accurate attenuation level.

A review of these traces led to the following observations:

1. Attenuation peaks were encountered in all motors upon ignition; the most severe being observed in the Genie tests where attenuation peaks exceeded the calibration limit of 20 db. The TX-280 motors indicated ignition peaks of approximately 0.5 db. on all channels. The Recruit motors indicated approximately 10 db. on X and Ku bands, and Ka band attenuation in excess of 20 db.

2. During motor operation, attenuation in all motors was essentially below the resolution capability of the microwave system (0.25 db). Considerable data reduction effort will be required to analyze very small attenuation levels as there are occasionally shifts in pre- and post-firing zero points as well as small shifts in transmitter signal strength.

3. On tail-off, the TX-280 and Recruit motors changed attenuation only slightly, while the Genie motors showed an increase to 6 to 8 db. at approximately 200 psi. Considerable plume-generated random noise was evidenced on the Genie for approximately 6 seconds after the start of tail-off. This is most likely caused by residual burning of liner and insulation inside the motor.

4. Some motor - to - motor inconsistencies were noted that have not been correlated to shifts in power levels because of the noise present on the traces. The magnitude of these inconsistencies does not exceed a total of 0.5 db. It is possible that by an analysis of the FM tapes by differential amplifier techniques these inconsistencies could be resolved.

Just prior to the last test, it was discovered that a relaxation of the elastic shock support for the X Band Klystron permitted the wave guide to touch the edge of the Klystron blower housing. Under severe vibration, the resulting impacts resulted in noise modulation of the Klystron. On the last test, this condition was eliminated and the noise level reduced considerably. It may be noteworthy that no positive signal level shift was noted on X Band for this test; thus, it is also possible that previous shifts of this nature may have been the result of Klystron vibration.

The output voltage and impedance characteristics of microwave diodes is such that it would be advisable to incorporate emitter-follower type signal conditioning elements at the detector elements to lower the input impedance to the long coaxial lines which conduct the detected signals to the instrument room. This will improve the signal to noise problem and aid in improving the system resolution.
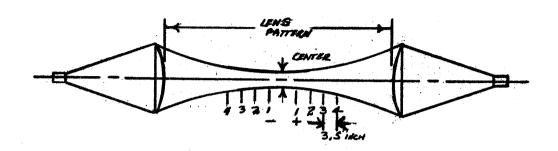
On the possibility that some of the signal level attenuation shifts noted on the transmitter could be caused by the pressure of infrared energy, tests were conducted in the laboratory by directing infrared energy into the X band receiver horn. No noticeable change was detected.

It is believed that the over-all system accuracy during the tests was within the previously stated range of 0.25 db. The unexplainable variations in attenuation levels, in most cases, fell within this range.

TABLE I

X BAND
LENS PATTERN TEST DATA

	Position Disc Dia.	Center (Values Below in db.)	+3.5"	+7"	+10.5"	+14"	-3.5"	-7"	-10.5"	-14"
37"	(6"	22	22	21	19	16.5	22	21	19	17
Lens	(5"	20	20.5	18	15	11.5	20.5	19	15.5	12.5
Spacing	(4"	14.5	15.5	13.5	10.5	8.5	15.5	14	11	8
	(3"	8.5	9	8.5	7	5	9	8.7	7.5	5.7
36"	6"	21	21	20.5	20	17	21	20.5	20	16.5
Lens	5"	20	20	18	18	15.5	20	17.5	16	14
Spacing	4"	15	16	15	11	8.5	16	13.5	10	8.5
	3"	9.5	9.5	8.5	6.25	--	9.5	9	8.5	6.25
35"	6"	22	22	20.5	20	15	22	20.5	19	15
Lens	5"	20	21.5	18.5	16	11.5	21.5	18.5	16	11
Spacing	4"	16.5	17	15	11	8.5	17	15	11.5	8.25
	3"	9.5	10	9.5	7.5	4.8	10	9.5	7.5	5
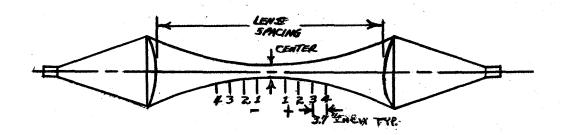
Lens Aperature	= 10"
Internal F.L.	= 14.5"
External F.L.	= 18" (Dez.)
Best Pattern Spacing	= 35"

TABLE II

Ku BAND
LENS PATTERN TEST DATA

	Position Disc Dia.	Center (Values Below in db.)	+3.5"	+7"	+10.5"	+14"	-3.5"	-7"	-10.5"	-14"
40"	(5"	28	28	26.5	24.5	23	28	26.5	24.5	23
Lens	(4"	24	22.5	21.5	21	20	22.5	21.5	21.5	20
Spacing	(3"	11	13.5	23.0	17	14	13.5	23	17	14
41"	(5"	28	28	26.5	24.5	23	28	26.5	24.5	23
Lens	(4"	24	22.5	21.5	21	20	22.5	21.5	21	20
Spacing	(3"	11	13.5	23	17	14	13.5	23	17	14
39"	5"	28	27.5	26.5	26	25	27.5	26.5	26	25
Lens	4"	24	23	22	21	20.5	23	22	21	20.5
Spacing	3"	12.5	15	23	18	13	15	23	18	13

Lens Aperature   = 6"
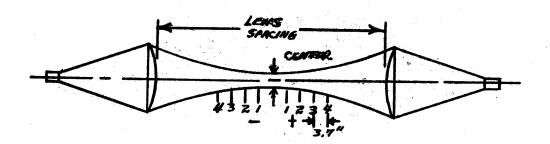
Internal F.L.   = 8.75

External F.L.   = 20" (Dez.)

Best Pattern Spacing = 39"

TABLE III

Ka BAND
LENS PATTERN TEST DATA

LENS SPACING · CENTER · 3.7"

Position Disc Dia.	Center	+3.7"	+7.4"	+11.1"	+14.8"	-3.7"	-7.4"	-11.1"	-14.8"
		(Values Below in db.)							
40" Lens Spacing 4"	25	24	24	24	19	25	24	23	18.5
3"	20	20	20	15	9	20	21	20	17
2.5"	15.5	16.5	15	12	8.5	16	16	14	9.5
39" Lens Spacing 4"	30	30	30	27	24	30	30	25	20
3"	23	21.5	19	14.5	10	22	22	20	16
2.5"	17	18	18	13.5	9	18	18	13	9
38.5" Lens Spacing 4"	25	25	25	23	21	25	25	21	19
3"	17	17	17	15	11	17.5	17	16	12.5
2.5"	15	15	14	10	7	15	15	14	9.5

Lens Aperature   = 6"

Internal F. L.   = 8.75

External F. L.   = 20"

Best Pattern Spacing = 39"

TABLE IV

RADAR ATTENUATION PREDICTION

	Genie	Recruit	TX-280
γ	6.08×10^{11}	2.11×10^{12}	5.69×10^{11}
h_e/cc	1.53×10^{10}	1.94×10^{8}	5.25×10^{8}
h_e/m^3	1.53×10^{16}	1.94×10^{14}	5.25×10^{14}
$h_e^{1/2}$	1.237×10^{8}	1.39×10^{7}	2.29×10^{7}

$$W_1 = 6.28 \times 10^{10} \text{ radians/sec}$$

	Genie	Recruit	TX-280
γ/W	9.0	33.6	9.1
$h_e^{1/2}/W$	1.9×10^{-3}	2.2×10^{-4}	3.6×10^{-4}
db/W	1.22×10^{-11}	5×10^{-14}	5×10^{-13}
db/m	0.75	3.14×10^{-3}	3.14×10^{-2}

$$W_2 = 1.256 \times 10^{11} \text{ radians/sec}$$

	Genie	Recruit	TX-280
γ/W	4.5	1.68×10	4.5
$h_e^{1/2}/W$	0.98×10^{-3}	1.1×10^{-4}	1.8×10^{-4}
db/W	3.5×10^{-12}	3.5×10^{-14}	10^{-13}
db/m	0.44	4.4×10^{-3}	1.2×10^{-2}

$$W_3 = 1.885 \times 10^{11} \text{ radians/sec}$$

	Genie	Recruit	TX-280
γ/W	3	1.12×10	3.0
$h_e^{1/2}/W$	6.6×10^{-4}	7×10^{-5}	1.2×10^{-4}
db/W	10^{-12}	10^{-14}	4×10^{-14}
db/m	0.19	1.9×10^{-3}	7.2×10^{-3}

Preliminary Design
10" Aperture Antenna Mount for
Microwave Measurement System

G.W.S. 11/10/64
Reference Dwg. FR-40541
Lens Dwg. DR-42305
Horn Dwg. CR-42258

Horn and Lens Shown
for Design Clarity.
These are not Part
of Frame Assembly

Preliminary Design
10" Aperture Antenna Mount for
Microwave Measurement System

G.W.S. 11/10/64
Reference Dwg. FR-40541

Clamp Detail
Not Shown

10" or Larger
Aluminum Channel

Figure 1.   Microwave Equipment as Modified to Provide Ku Band Measurements.

KLYSTRON
POWER SUPPLY

KLYSTRON

6 DECIBEL PAD

COUPLER

CRYSTAL DETECTOR

VARIABLE PRECISION
ATTENUATOR

CRYSTAL DETECTOR

RECORDER

D.C. AMPLIFICATION
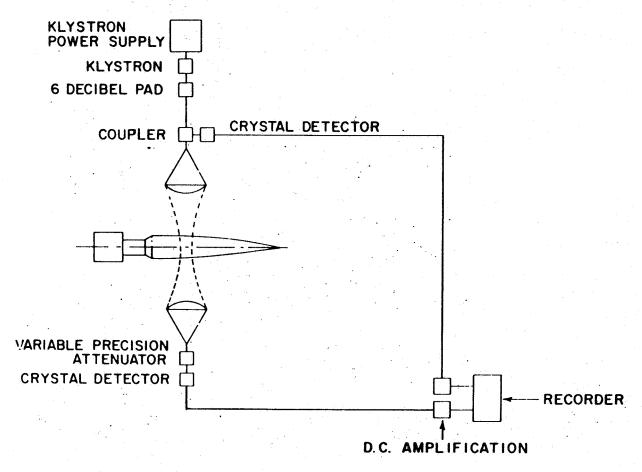
Figure 2. Microwave Attenuation Measuring System.

PLEXIGLAS SHEET
(0.112" THICK)

MICROWAVE ABSORBER DISC
(ECCOSORB AN 73)

TRANSMITTING
LENS

ELECTRIC
MOTOR

RECEIVING
LENS

HOLDER

TRACK
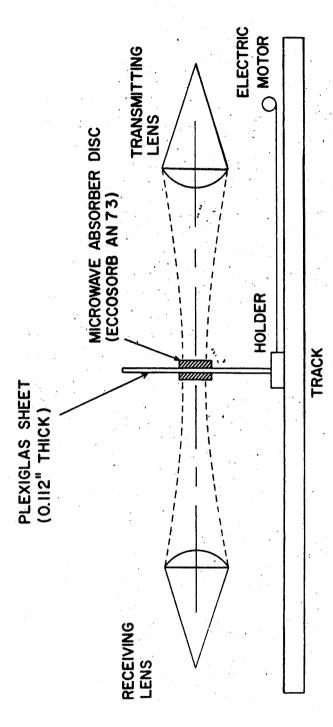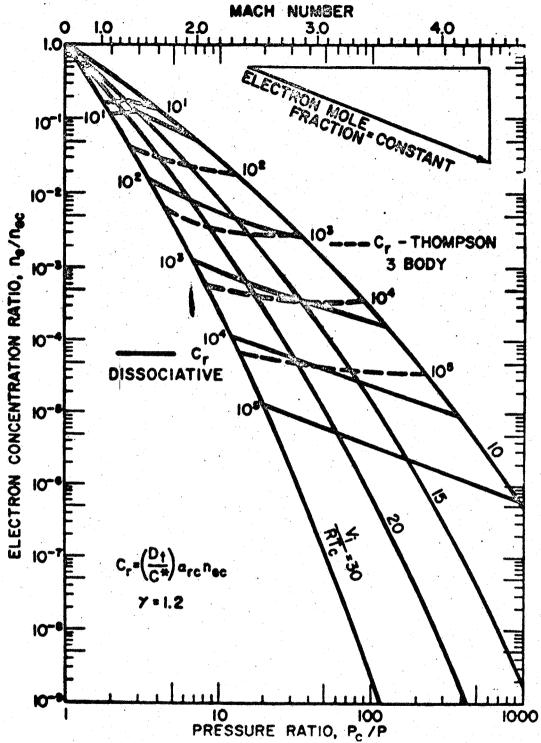
Figure 3. Dielectric Lens Microwave Energy Profile Measuring System.

Figure 4.   Electron Decay During Nozzle Expansion.
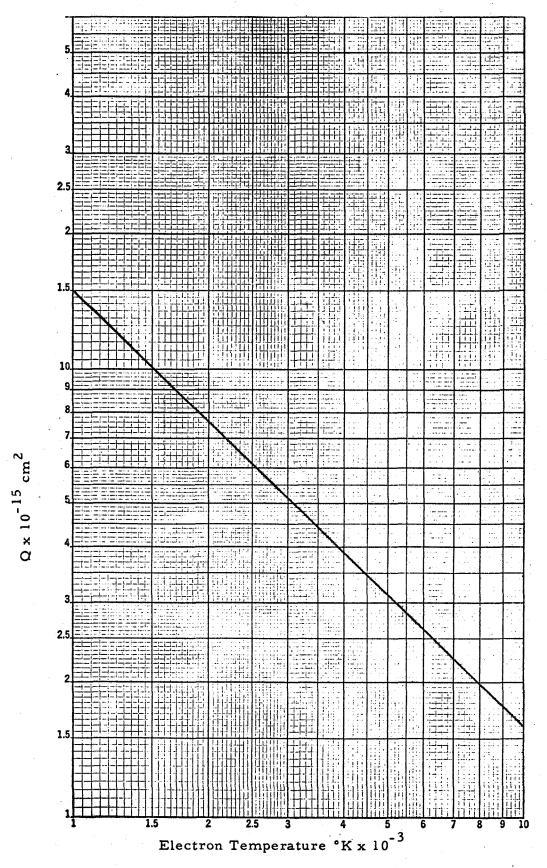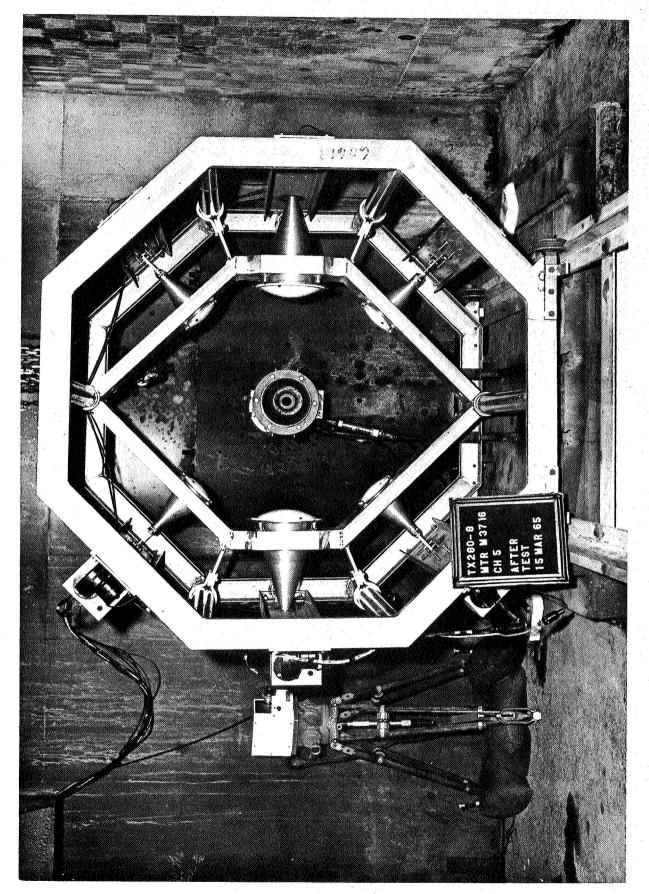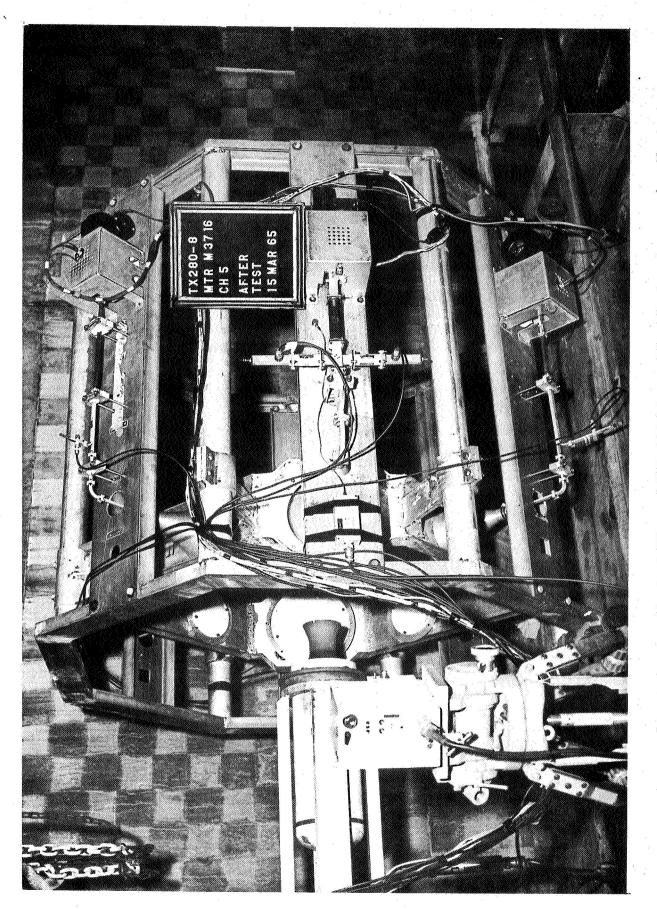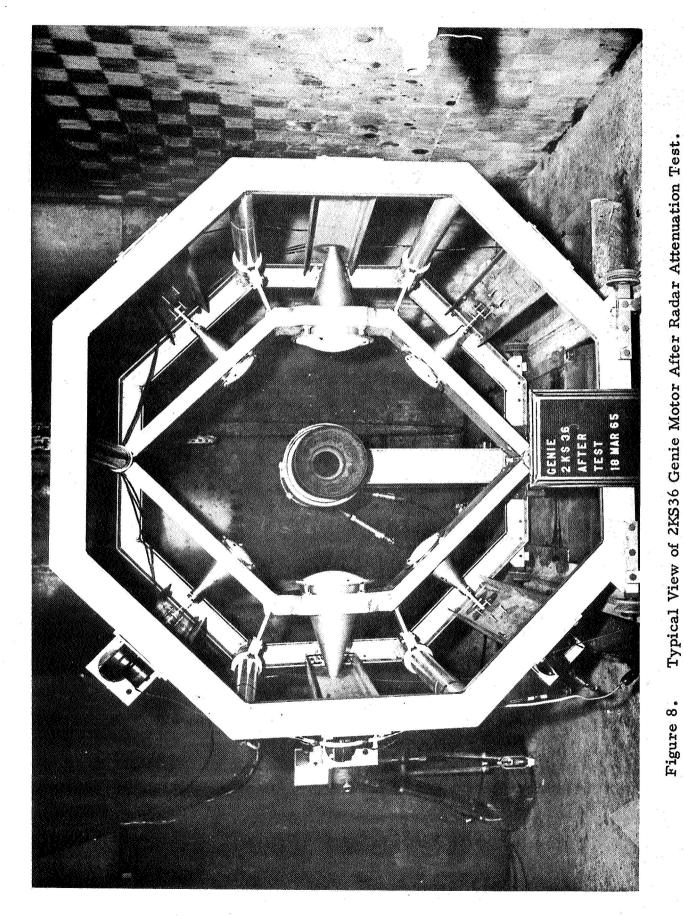
Figure 5.   Electron Collision Cross-Section of Water.

Figure 6.   Typical View of TX-280 Motor After Radar Attenuation Test.

TX280-8
MTR M 3716
CH 5
AFTER
TEST
15 MAR 65

Figure 7.   Another Typical View of TX-280 Motor After Radar Attenuation Test.

Figure 8.   Typical View of 2KS36 Genie Motor After Radar Attenuation Test.
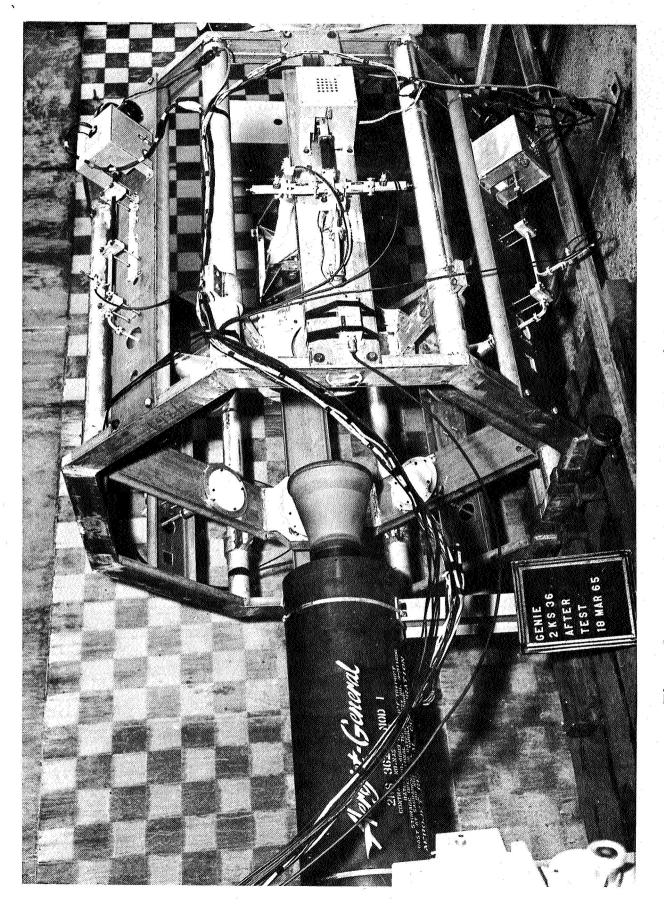
Figure 9.   Another Typical View of 2KS36 Genie Motor After
Radar Attenuation Test.
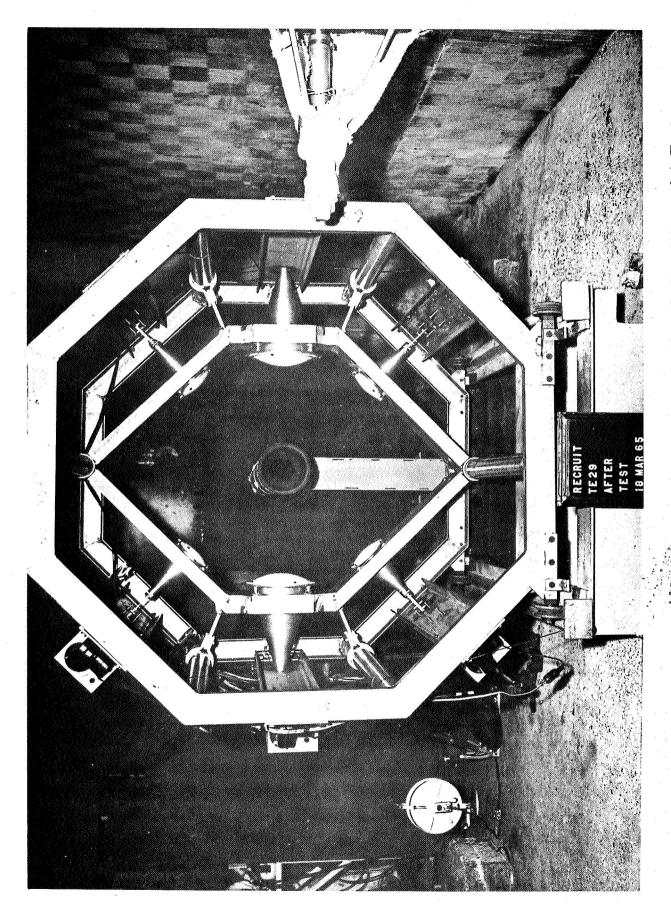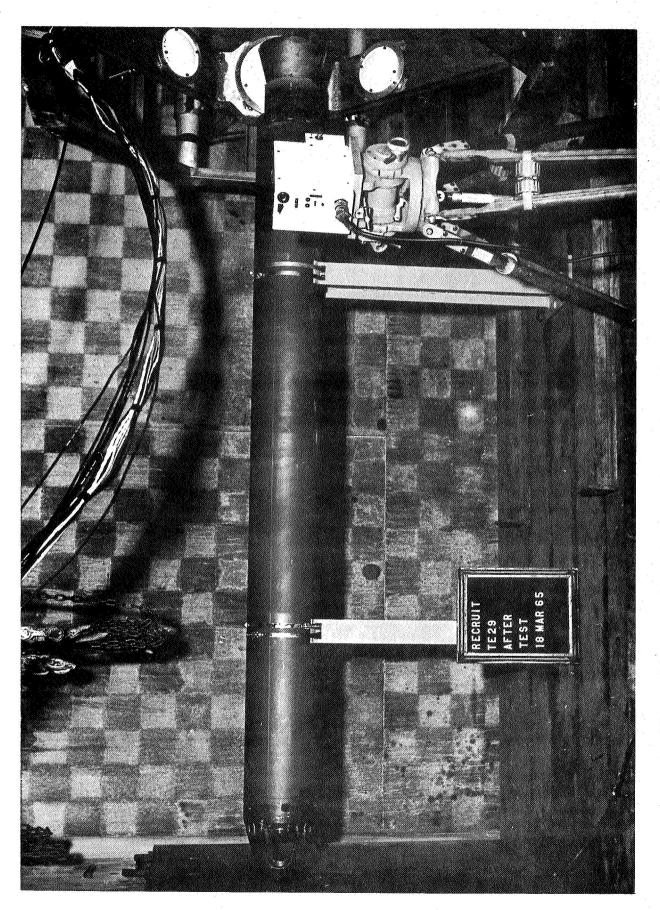
Figure 10. Typical View of TE-29 Recruit Motor After Radar Attenuation Test.

RECRUIT
TE 29
AFTER
TEST
18 MAR 65

Figure 11.   Another Typical View of TE-29 Recruit Motor After Radar Attenuation Test.
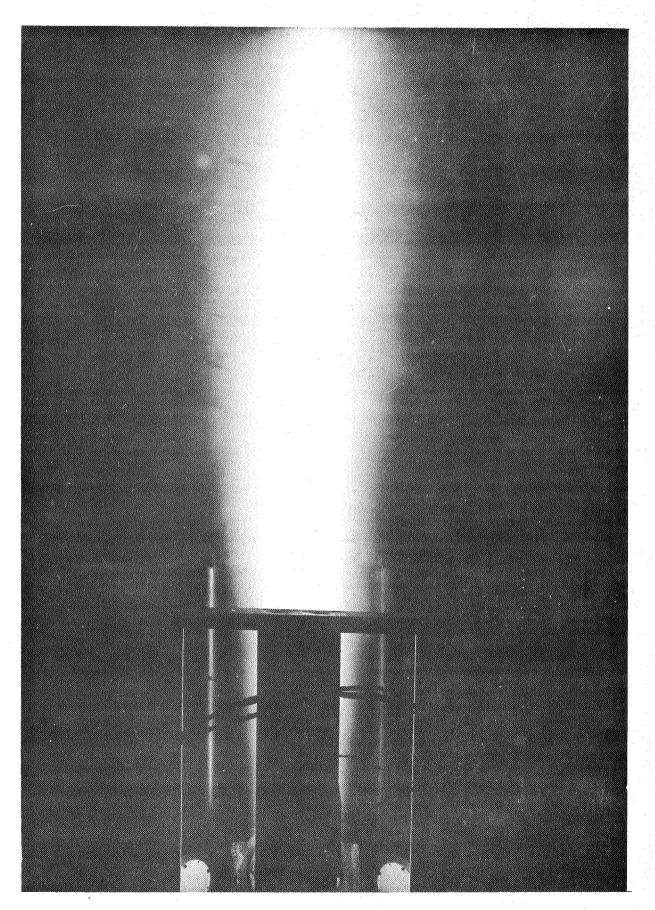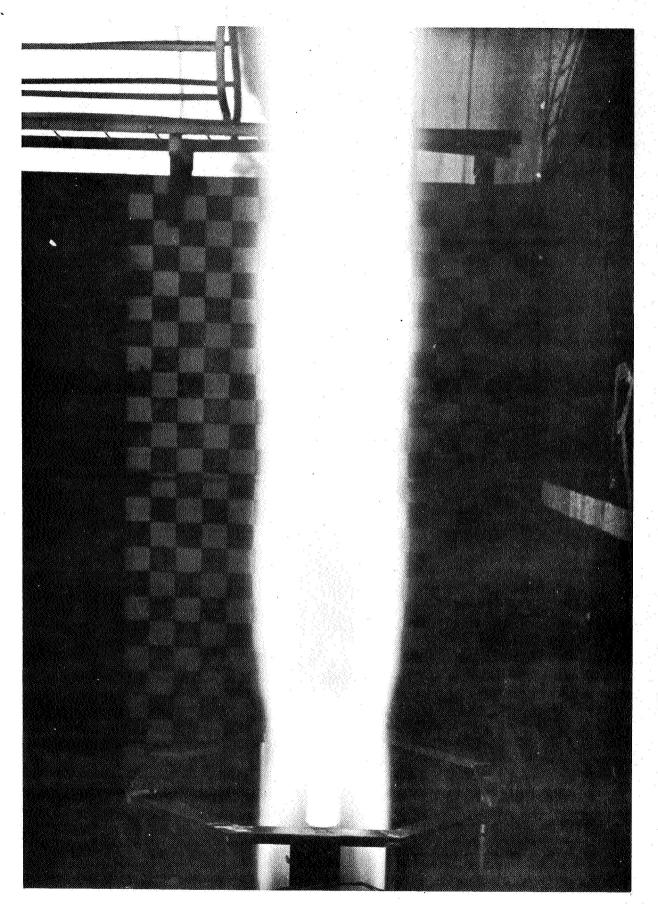
Figure 12. Exhaust Plume of a Typical TX-280 Motor During
Radar Attenuation Test.

Figure 13.   Exhaust Plume of a Typical 2KS36 Genie Motor During Radar Attenuation Test.
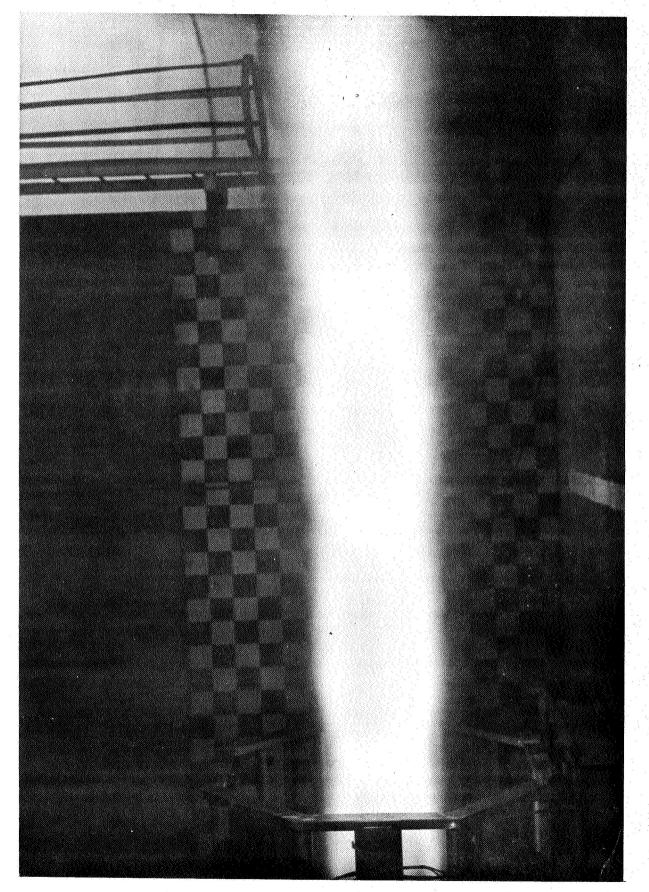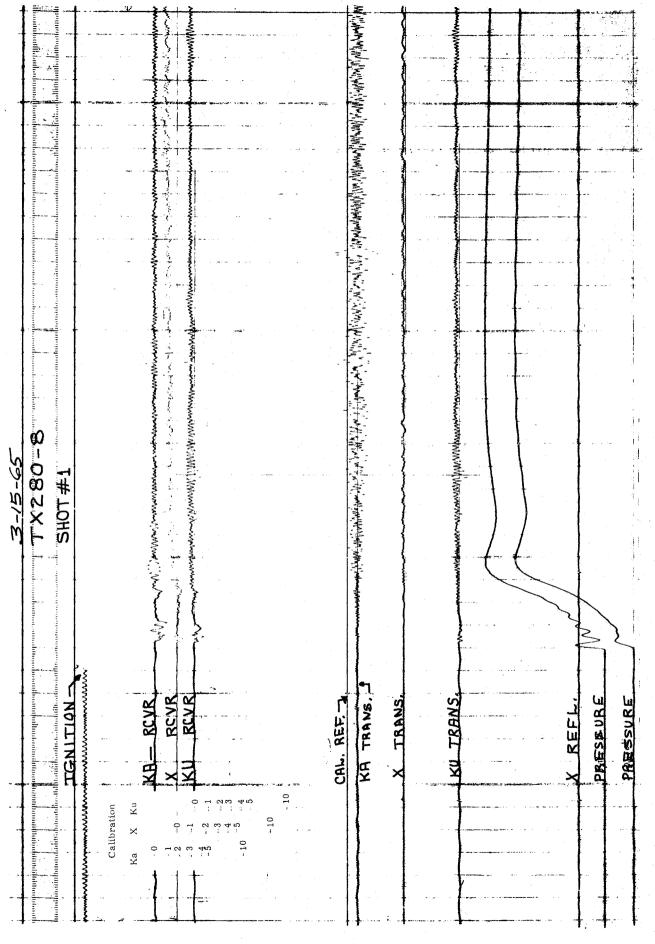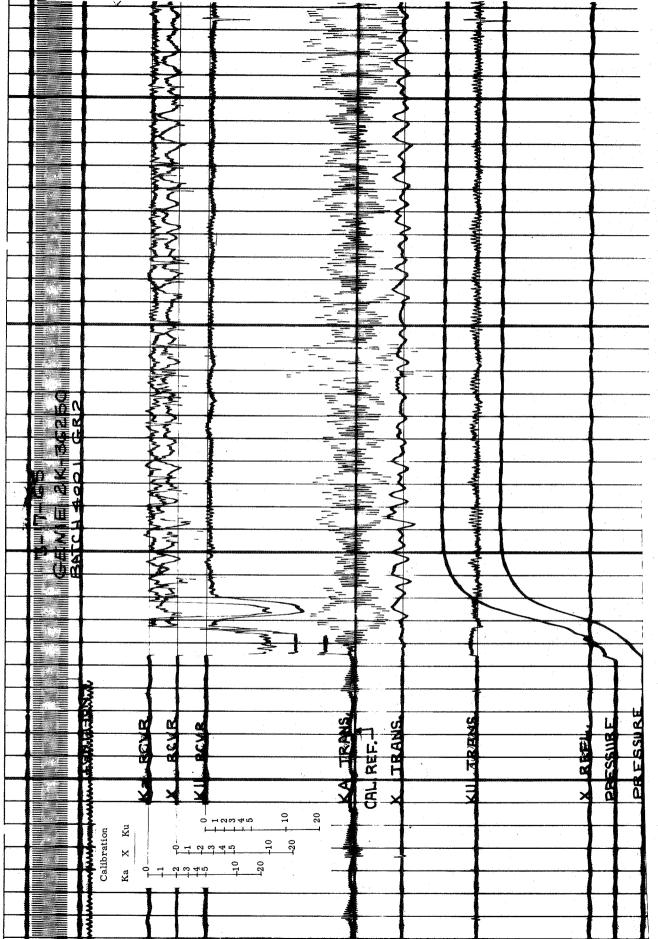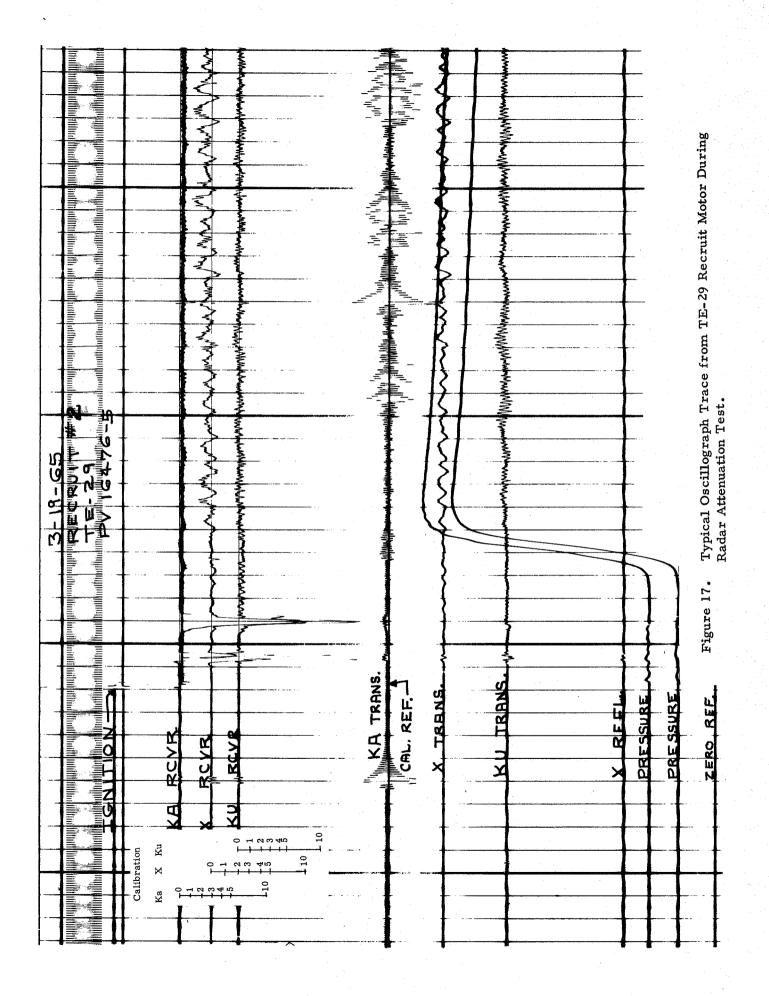
Figure 14. Exhaust Plume of a Typical TE-29 Recruit Motor During
Radar Attenuation Test.

3-15-65

TX280-8

SHOT #1

IGNITION

Calibration

Ka X Ku

KA — RCVR

X RCVR

KU RCVR

CAL. REF.

KA TRANS.

X TRANS.

KU TRANS.

X REFL.

PRESSURE

PRESSURE

Figure 15. Typical Oscillograph Trace from TX-280 Motor Radar Attenuation Test.

Figure 16.   Typical Oscillograph Trace from 2KS36 Genie Motor During Radar Attenuation Test.

Figure 17. Typical Oscillograph Trace from TE-29 Recruit Motor During Radar Attenuation Test.

APPENDIX   A

MICROWAVE EQUIPMENT LIST

10 KMC Range System Microwave Equipment List

1. Klystron Power Supply
    Sperry Microwave Electronics Company
    Mode 62A1

2. Klystron
    Raytheon Model RK6312
    8.5 KMC to 10 KMC   40 mw.

3. Frequency Meter
    Waveline, Incorporated, Model 698DR
    Calibration ± 0.08 percent

4. Precision Variable Attenuators
    Waveline, Incorporated, Model 612
    Calibration ± 0.1 db at 10 KMC

5. Broadwall Coupler
    Waveline, Incorporated, Model 674-30

6. Crystal Mounts
    Waveline, Incorporated, Model 612
    with 1N21C Sylvania Diodes

7. Microwave Horns (Aluminum) 10 Inch Aperture
    Shop Fabricated per Thiokol Drawing No. CR-42305

8. Microwave Lenses (Teflon) 10 Inch Aperture
    Shop Fabricated per Thiokol Drawing No. CR-42258

20 KMC Range System Microwave Equipment List

1. Klystron Power Supply
   Sperry Microwave Electronic Company
   Model 62A1

2. Klystron
   Electra Megadyne Incorporated, Model R9621
   20 KMC to 24 KMC   80 mw

3. Frequency Meter
   Waveline, Incorporated, Model 898DR
   Calibration $\pm$ 0.08 percent

4. Precision Variable Attenuator
   Waveline, Incorporated Model 812
   Calibration at 20 KMC $\pm$ 0.1 db.

5. Broadwall Coupler
   Waveline, Incorporated, Model 874-30

6. Crystal Mounts
   Waveline, Incorporated, Model 815
   with 1N26 Sylvania Diodes

7. Microwave Horns and Lenses
   Same as for 30 KMC range except feed adaptation
   is for RG53-U waveguide

30 KMC Range System Microwave Equipment List

1. Klystron Power Supply
   Sperry Microwave Electronics Company
   Model 62A1

2. Klystron
   Electra Megadyne, Incorporated, Model R9518
   27.8 to 32.2 KMC   80 mw

3. Frequency Meter
   FXR Model MC619
   Calibration $\pm$ 0.08 percent

4. Precision Variable Attenuator
   Waveline, Incorporated, Model 1012
   Calibration at 30 KMC $\pm$ 0.1 db

5. Broadwall Coupler
   Waveline, Incorporated, Model 1074-30

6. Crystal Mounts
   Waveline, Incorporated, Model 1014
   with 1N53C Sylvania Diodes

7. Microwave Horns (Aluminum) 6 Inch Aperture
   Shop Fabricated per Thiokol Drawing No. CR-40533

8. Microwave Lenses (Teflon) 6 Inch Diameter
   Shop Fabricated per Thiokol Drawing No. CR-40534

1.   D. C. Amplifiers
Dana Laboratories, Incorporated
Model 2200D
Input Impedance: -10 megohms
D. C. Linearity: ± 0.01 percent
Frequency Response: (Peak Amplitude) ± 1 db   0 to 20 KC
Noise (referred to input): 4 mv rms, full bandwidth at gain
   of 1000
Drift (constant temperature): ± 0.02 percent in 200 hours

2.   F. M. Record/Reproduce System
Ampex Corporation
Model FR-100 with 1 inch tape and 14 channel recording head
   (11 F. M. channels and 1 direct)
Frequency Response: at 60 ips. 0-10 KC FM and 0-100KC direct
Signal/Noise: at 60 ips. 48 db.
Input Level: 1 vold RMS for normal recording level
Input Sensitivity: 0.7 to 50 volts RMS
Input Impedance: 100,000 ohms unbalanced to ground.
Output Impedance: 10,000 ohms unbalanced to ground.
Harmonic Distortion: at 60 ips = 1.5 percent
F. M. Linearity: ± 1 percent of full bandwidth
F. M. Drift: 1 percent full-scale in 2 hours after warm-up
   of 30 minutes

APPENDIX   B

CALIBRATION CERTIFICATION ON MICROWAVE EQUIPMENT

HEADQUARTERS

U. S. ARMY MISSILE SUPPORT COMMAND
U. S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

ARMY MISSILE COMMAND CALIBRATION CENTER

MICROWAVE STANDARDS LABORATORY

REPORT OF CALIBRATION

VARIABLE ATTENUATOR

MFG___*WAVELINE*_____

TYPE_*812*___SERIAL__*3424*_____

SUBMITTED BY

___*THIOKOL___CHEM CORP*

_____

    Measurements are performed under Standard Laboratory Environmental Conditions of Temperature and Humidity. The power applied to the attenuator was less than ___*·/*___ milliwatts. The VSWR presented to each terminal of the attenuator was less than *1.05*. Calibrating frequencies are in error by less than ___*·/*___ percent. The attenuator was calibrated by making attenuation difference measurements. The zero position of the dial was used as the reference position.

    VARIABLE ATTENUATORS OTHER THAN DIRECT READING.

    The calibration tabulation attached to this report of calibration compares the graduations of the dial of the attenuator and the measured attenuation difference.

    VARIABLE DIRECT READING ATTENUATORS.

    The dial of direct reading attenuators is correct within the manufacturer's tolerances. (When supplied with direct reading attenuators, a calibration tabulation may indicate dial errors in excess of the manufacturer's tolerances.)

Test No: *65-OLM- 001*
Sheet 1 of
Date: *15 JAN 65*

TEST PERFORMED BY:

Tom Ray

FREQ = 20.0GC — INSERTION LOSS = .12DB

Dial Graduation of Device	Value of Parameter Measured (DB)
067	1.0
086	2.0
107	3.0
113	4.0
123	5.0
132	6.0
141	7.0
148	8.0
156	9.0
163	10.0
194	15.0
221	20.0
243	25.0
262	30.0
276	35.0
282	37.62

FREQ = 21.06GC — INSERTION LOSS = .10DB

Dial Graduation of Device	Value of Parameter Measured (DB)
066	1.0
085	2.0
099	3.0
111	4.0
120	5.0
129	6.0
138	7.0
146	8.0
153	9.0
160	10.0
192	15.0
218	20.0
240	25.0
259	30.0
223	35.0
282	38.96

Test No: 65-OLM-001
Date: 15 JAN 65

TEST PERFORMED BY:

Tom Ray

Dial Graduation of Device *FREQ = 19.04*	Value of Parameter Measured *(DB)* *INSERTION LOSS = .18DB*	Dial Graduation of Device	Value of Parameter Measured
069	1.0		
089	2.0		
104	3.0		
115	4.0		
126	5.0		
135	6.0		
144	7.0		
152	8.0		
160	9.0		
167	10.0		
198	15.0		
225	20.0		
248	25.0		
266	30.0		
280	35.0		
282	35.86		

Test No: 65-OLB-001
Date: 15 JAN 65

TEST PERFORMED BY:

Tom May

HEADQUARTERS

U. S. ARMY MISSILE SUPPORT COMMAND
U. S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

IN REPLY
REFER TO

ARMY MISSILE COMMAND CALIBRATION CENTER

MICROWAVE STANDARDS LABORATORY

REPORT OF CALIBRATION

VARIABLE ATTENUATOR

MFG _WAVE LINE_____

TYPE _1012_ SERIAL _3/32_____

SUBMITTED BY

___THIOKOL_____

Measurements are performed under Standard Laboratory Environmental Conditions of Temperature and Humidity. The power applied to the attenuator was less than __.1__ milliwatts. The VSWR presented to each terminal of the attenuator was less than __1.05__. Calibrating frequencies are in error by less than __.1__ percent. The attenuator was calibrated by making attenuation difference measurements. The zero position of the dial was used as the reference position.

VARIABLE ATTENUATORS OTHER THAN DIRECT READING.

The calibration tabulation attached to this report of calibration compares the graduations of the dial of the attenuator and the measured attenuation difference.

VARIABLE DIRECT READING ATTENUATORS.

The dial of direct reading attenuators is correct within the manufacturer's tolerances. (When supplied with direct reading attenuators, a calibration tabulation may indicate dial errors in excess of the manufacturer's tolerances.)

Test No: 65-0213-012
Sheet 1 of
Date: 23 FEB 65

TEST PERFORMED BY:

Willie R. Carter

FORM SMIDW-OL-23, 1 JUL 64

B-5

CALIBRATION FREQ = 30 KMC
CALIBRATION ACCURACY ± .1 DB OR 1% WHICHEVER IS
GREATEST
DIAL READJUSTED TO ZERO

Dial Graduation of Device	Value of Parameter DB Measured	Dial Graduation of Device	Value of Parameter Measured
.068	1		
.082	2		
.092	3		
.099	4		
.107	5		
.132	10		
.153	15		
.170	20		
.187	25		
.202	30		
.216	35		
.227	40		
.238	45		
.246	50		

TEST PERFORMED BY:

Willie R. Carter

Test No: 65-OLM-012
Date: 23 FEB 65

IN REPLY
REFER TO

ARMY MISSILE COMMAND CALIBRATION CENTER

MICROWAVE STANDARDS LABORATORY

REPORT OF CALIBRATION

VARIABLE ATTENUATOR

MFG _WAVELINE_

TYPE _612_ SERIAL _3096_

SUBMITTED BY

THIOKOL

Measurements are performed under Standard Laboratory Environmental Conditions of Temperature and Humidity. The power applied to the attenuator was less than ___/___ milliwatts. The VSWR presented to each terminal of the attenuator was less than _1.05_. Calibrating frequencies are in error by less than ___./___ percent. The attenuator was calibrated by making attenuation difference measurements. The zero position of the dial was used as the reference position.

VARIABLE ATTENUATORS OTHER THAN DIRECT READING.

The calibration tabulation attached to this report of calibration compares the graduations of the dial of the attenuator and the measured attenuation difference.

VARIABLE DIRECT READING ATTENUATORS.

The dial of direct reading attenuators is correct within the manufacturer's tolerances. (When supplied with direct reading attenuators, a calibration tabulation may indicate dial errors in excess of the manufacturer's tolerances.)

Test No: 65-CLM-011
Sheet 1 of
Date: 19 FEB 65

TEST PERFORMED BY:

FORM SMICW-OL-23, 1 JUL 64

CALIBRATION 1 KLG' 1000
ACCURACY OF MEASUREMENT = ±.1 DB OR 1%
INSERTION LOSS WITH DIAL AT ZERO = .06 DB

Dial Graduation of Device	Value of Parameter Measured	Dial Graduation of Device	Value of Parameter Measured
.026	1	--------	-------
.036	2	--------	-------
.044	3	--------	-------
.050	4	--------	-------
.056	5	--------	-------
.076	10	--------	-------
.092	15	--------	-------
.105	20	--------	-------
.128	30	--------	-------
.138	35	--------	-------
.148	40	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------
--------	-------	--------	-------

Test No: 65-OLM-011
Date: 19 FEB 65

TEST PERFORMED BY:
B.L. Ferrell